DYNAMIC SIMULATION OF INNOVATIVE AIRCRAFT AIR CONDITIONING

C. Müller[1], D. Scholz[1], T. Giese[2],

[1]Department of Automotive and Aeronautical Engineering
Hamburg University of Applied Sciences
Berliner Tor 9, 20099 Hamburg
Germany

[2]Validation & Verification, Airbus Deutschland GmbH
Kreetslag 10, 21129, Hamburg
Germany

ABSTRACT

The development of innovative air conditioning systems for passenger aircrafts requires the application of dynamic simulation. FLECS, the "Functional Model Library of the Environmental Control System", was programmed to support such development processes of environmental control systems (ECS). FLECS offers a library with generic models from small ECS components up to the whole aircraft cabin. Fundamental to FLECS is the functional simulation in a MATLAB/Simulink environment based on a generalized volume and generalized resistances – mass flow resistances as well as heat flow resistances. Based on these generalized elements, specialised components like isobaric volumes and fan components were derived. Using measured datasets recorded during a test flight of an Airbus A340-600, a set of duct components as well as a cabin model was validated. The measured data was matched in both cases by the simulated response of the system. The validated duct components and the cabin model were used to simulate the control behaviour of an ECS. The cabin model of this simulation consisted of 2 zones of a single aisle aircraft. A highly dynamic test case was defined. The simulated behaviour of the system was plausible and could be well interpreted.

1. INTRODUCTION

Environmental control system: Heating, cooling, ventilation, distribution and purification of the air as well as control of temperature, pressure and humidity are the tasks of an environmental control system (ECS) on board of aircrafts. Already in the early stage of the aircraft development different system architectures need to be compared. Trade studies need to be performed to evaluate one system architecture against another alternative, in order to be able to choose the most suitable one in the end [1]. The many functions of an ECS require many components, which need to be sized and tuned to each other in an optimum way.

Simulation: The ECS development as just described is achieved today with the help of simulation. Three main areas of simulation in the ECS development may be differentiated:

- the calculation of three-dimensional (3D) flow fields in components of the environmental control system or the aircraft cabin by means of Computational Fluid Mechanics (CFD) [2],
- the simulation of one-dimensional (1D) flow in air distribution networks,
- the functional simulation of the environmental control system and the cabin.

An overview of the application of different areas of simulation in ECS is given in [3]. The functional simulation is the topic of the project FLECS. It encompasses especially the description of thermodynamics, mechanics and control aspects of the ECS and its components with an emphasis on their dynamics and interaction.

Functional library: The project's aim of FLECS is to support design activities for innovative air conditioning systems in future passenger aircrafts. In order to achieve this, a model library based on the commercial standard software MATLAB/Simulink [4], [5] is programmed. Finally, the library will contain generic simulation models of all relevant components that can be found in the air conditioning system and of thermally relevant components in the aircraft cabin. Information on the FLECS project is given in [6] and [7].

Literature review: A review [8] showed that many approaches exist of 1D, 3D or functional simulation that have been or could be applied to ECS development. Publications with aircraft ECS applications are e.g. [9], [10], [11].

Innovative technologies in the area of ECS in aircrafts are e.g. bleedless aircraft, vapor cycle system, new control concepts, increase of cabin air humidity and galley cooling. These new technologies require standard components as well as new ones that are modelled in the FLECS project. In this way a functional ECS simulation is built up that ensures the safe introduction and integration of these new technologies in the aircraft.

Static design of the ECS: The environmental control system can be designed statically from top level aircraft requirements like number of passengers, mission range of the aircraft, operational envelope, maximum cabin altitude etc., if additionally the different heat loads and heat capacities inside the cabin are known or estimated. Results from a static ECS design are for example the from a static ECS design are for example the necessary pack and recirculation mass flow. Requirements for the general design of ECS can be found in [12] and [13].

Dynamical design of the ECS: Based on parameters from the static ECS design, a dynamical simulation can be built up. The design of an ECS has to ensure, that different time dependent scenarios, like the pull down case (cooling) or pull up case (heating) are fulfilled [12]. With a simulation it can be assured that dynamic requirements are met. A simulation can furthermore be used to determine the parameters of the various controllers in the system, as there are the pack controllers or the cabin & duct controller. Information on temperature control in aircrafts can be found in [14].

This paper builds on a first paper on FLECS [15] in which a) the task of FLECS in the industrial ECS development process was explained together with b) fundamentals of the simulation of generalized volumes and generalized mass flow resistances as well as generalized heat flow resistances for conduction, convention and radiation (with mass flows of pre-dominantly dry air with water vapour and CO_2). Necessary information from [15] is summarized here in Section 3 in order to lay the ground for the explanation of an air distribution model as well as a cabin model being validated with measured data. The validated models are then used to investigate the control behaviour of an ECS of an aircraft with 2 cabin zones. After all of this, the way is paved for further applications of FLECS with respect to innovative aircraft air conditioning systems.

2. AIRCRAFT CABIN TEMPERATURE CONTROL AND VENTILATION

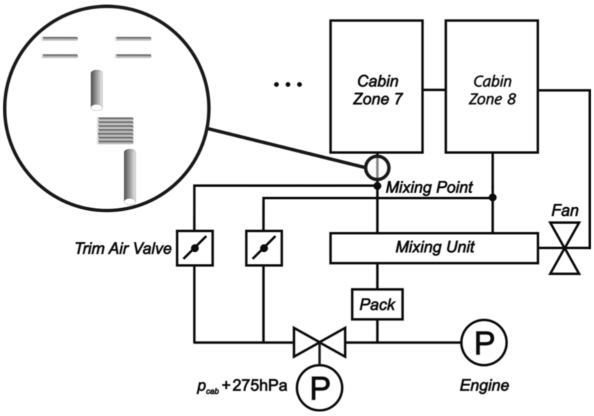

FIG. 1 Schematic drawing of the environmental control system. The marked region is shown in detail in FIG 3.

The principal configuration of an ECS is shown in FIG. 1. A cabin is divided into cabin zones. The temperature in each zone is controlled by an independent trim air valve. Conditioned air from the air generation packs and recirculated air from the cabin are mixed inside the mixing unit. From the mixing unit the air flows to the mixing point, where a small amount of hot trim air is added to achieve the selected cabin temperature.

The cabin zone with the lowest target temperature defines the required temperature inside the mixing unit. The trim air valve of this cabin zone is (almost) closed. The opening angles of the trim air valves of the other zones are opened that much as to allow enough hot air to pass into the respective duct to the cabin to achieve the demanded cabin zone air temperature. For an ECS two independent controller types are used to ensure all this: The pack controller controls the pack and hence the pack air temperature. The cabin & duct controller controls primarily the opening angle of the trim air valve and hence the cabin zone temperature. Details of control algorithms of existing aircraft are proprietary data of the respective equipment supplier.

3. FUNCTIONAL SIMULATION

During early aircraft program concept phases there is the need to **investigate** a large number of potential **system architectures** in a short time frame with the help of simulation, to find the best candidates for an optimum architecture. After down selection of system architectures, simulation models need to be further detailed giving a better insight into the expected system behaviour.

FLECS supports these activities with system **models based on MATLAB/Simulink** generic components. The description of each component consists of a set of state variables and a parameter set. Each state variable is related to a state equation. At each time step during a dynamic simulation all state equations have to be solved by integration of the differential equation. Starting from the initial conditions, the integration of each state variable is based on its value from the previous time step and on the values from the previous time step of other state variables (see FIG. 2). MATLAB/Simulink provides a powerful software platform, which enables to solve state equations. The user may choose among different integration algorithms.

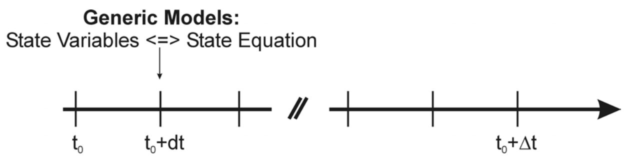

FIG. 2 Principal of a dynamic simulation.

The FLECS database follows a strictly **modular approach** [15]. The bases of the library are sub-components, representing generic thermodynamic models or fluid dynamic processes. Sub-components are assembled to basic components, like generalized volumes and generalized resistance elements, and to aircraft specific components, like cabin models or fans.

It is assumed that the airflow is composed not only of dry air, but also of a fraction of **water vapour** and a fraction $\mathbf{CO_2}$. The input and output variables for a volume element have to be adapted to account for all constituents: air, water and CO_2. The composition of the gas mixture cannot be assumed constant, it is rather a time dependant variable. Therefore the different contents of water vapour ($x_{H2O,gas}$), CO_2 (x_{CO2}) and water ($x_{H2O,liquid}$) have to be considered separately.

The **volume component** [15] is parameterised by the value of a constant volume. The state variables are the pressure, the density, the temperature and the different percentages of gaseous water, CO_2 and liquid water: $x_{H2O,gas}$, x_{CO2} and $x_{H2O,liquid}$.

With respect to the volume, the state equation for the temperature follows from the enthalpy equation of the volume. The state equation for the density (or the mass of the gas) follows from the continuity equation. The pressure follows from the ideal gas law.

The mass flow of the air, the density (respectively the mass of air), the temperature and the percentages $x_{H2O,gas}$, x_{CO2} and $x_{H2O,liquid}$ are all input variables to the volume element. Special volumes, named **mixing unit**, can handle the processes of condensation and evaporation.

The FLECS database is built for applications where the flow velocities are much smaller than the velocity of sound, therefore the kinetic energy at the start and at the end state of a system can be neglected.

Flow **resistance components** [15] fix the mass flow in the network. These resistance elements are always linked to a block, which has a defined pressure, density and temperature. From the known pressure difference (negative or positive) the mass flows can be calculated based on the averaged flow velocity. The important variables, which have to be known, are density and temperature. These variables are given as input parameters to the flow resistance element. Laminar and turbulent flow can be handled as well as incompressible and compressible flow.

One resistance component is the **tube**. The parameter set for a tube contains the length, the diameter and the minor loss coefficient. Circular as well as elliptical cross sections (see FIG. 3) can be parameterised. Density and temperature are also input parameters to the tube.

Two different types of flow resistances have to be distinguished. Generalised flow resistances calculate the pressure drop from the mass flow with an equation. Specialised flow resistances like a **fan** determine the pressure drop from a chart known as characteristic map.

Three different heat transfer processes can be distinguished and are modelled in FLECS [15]: conduction, convection and radiation of heat. A FLECS model of such a process is called **heat transfer unit**. In combination with volume elements various dynamic models of a **heat exchanger** can be built.

4. SIMULATION AND VALIDATION OF THE THERMAL BEHAVIOR OF AN AIRCRAFT CABIN

Single FLECS components were checked for stability and real time capability. Simulation results obtained with FLECS components have been compared with results generated by other flow system simulation programs [8], [15], [16].

The aim is now to validate FLECS components in a larger aircraft context as it is needed for ECS modelling. In a first step, an **air distribution network** as shown in FIG. 3. is applied. This network is part of the environmental control system of an aircraft (see FIG. 1).

The network consists of ducts that distribute the air from a mixing point into the respective cabin zone. In the mixing point a cold air flow coming from the mixing unit is mixed with hot trim air (compare with explanations in Section 2).

The air is pushed into the network via the supply duct. From the supply duct the air is channelled through 7 riser ducts and into an oval duct. At the outlet of the oval duct the airflow is split into 4 cross ducts. Finally the air enters the cabin through the cabin inlets.

Each duct is characterised by its length, wall thickness, thickness of the isolation and diameter (or major and minor axis in case of the oval duct).

A simulated duct component can be generated by a combination of a flow resistance and a volume (see FIG. 4). In order to model the correct dynamics of a long duct, it can even be built up from a combination of several flow resistances and several volumes. Through the duct wall heat transfer takes place. Two different processes have to be considered: a) heat convection between the airflow in the duct and the wall and b) the conduction through the wall and the isolation.

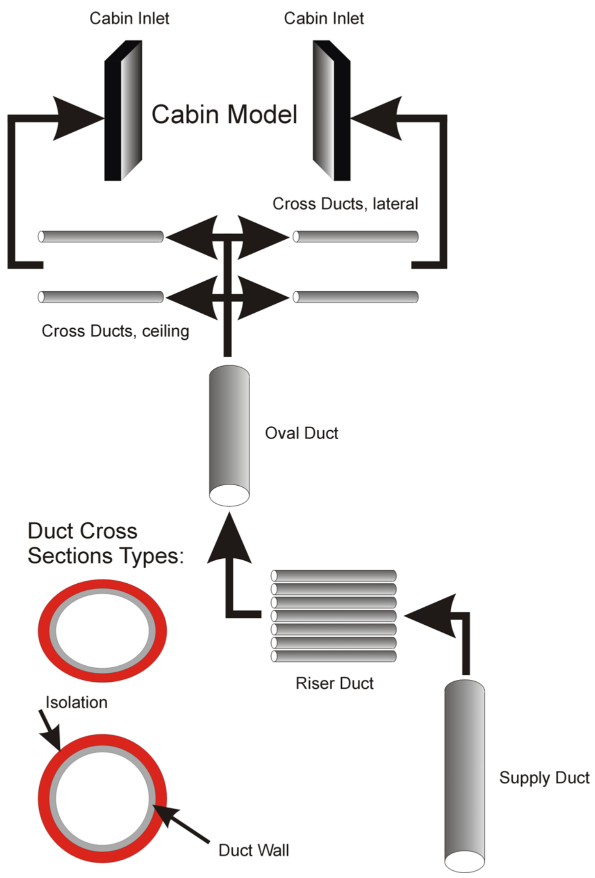

FIG. 3 Air distribution network consisting of a supply duct, riser ducts, an oval duct and 2 ceiling cross ducts and 2 lateral cross ducts. The different cross sections types (circular, elliptic) are shown.

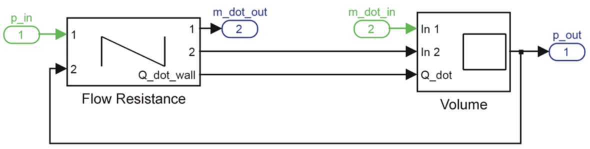

FIG. 4 Simulink configuration of a duct consisting of a flow resistance and a volume. Heat is transferred through the duct wall.

The convection heat transfer coefficient follows from the flow properties characterised by the Reynolds number. The heat conductivity coefficient is determined from the thickness of the wall and the isolation and the thermal properties of the two materials. Another important parameter for the heat transfer is the ambient temperature of the air surrounding the ducts.

Both the wall and the isolation are considered as thermal capacity. A thermal capacity is defined by the mass and the specific heat capacity. Using the library various duct and isolation geometries can be modelled easily.

In a second step, a **cabin model** is simulated. A cabin model can be described as a combination of a volume and a heat transfer unit (see FIG. 5).

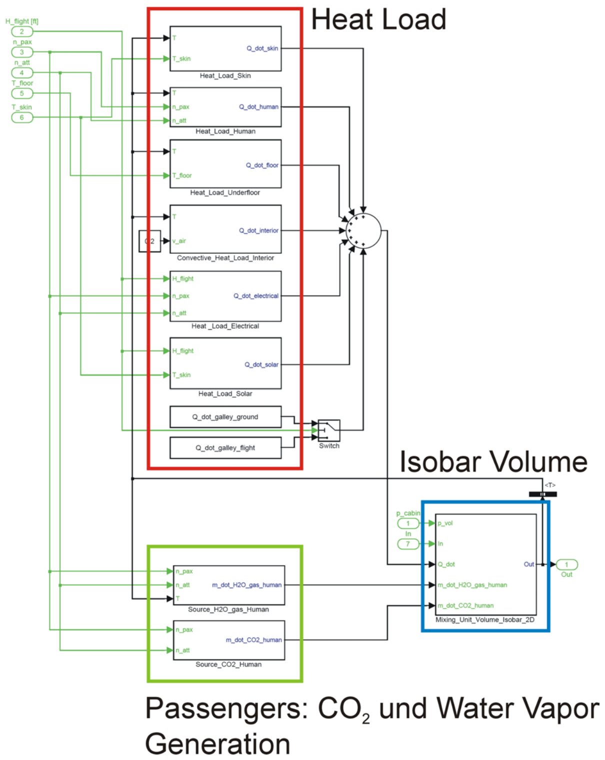

FIG. 5 Simulink configuration of a cabin model. The components marked red define the different heat loads. The region marked blue characterises the isobaric air volume. The components marked green calculate the CO_2 and the water vapour generated by the passengers.

The cabin is exposed to different **heat loads**: a) Conductive heat transfer takes place through the skin of the aircraft. b) Every passenger introduces a heat load into the system. c) Heat is transferred through the cabin floor into the under floor area of the aircraft. d) The heat load of the electrical equipment has a constant contribution and a contribution, which is dependant of the number of passengers. e) A solar heat flux enters the cabin through the windows. f) The heat load of the galley is considered constant.

The **thermal capacity** of the cabin is lumped into a single component to which all the cabin interior and lining contributes. This thermal capacity is defined by the mass and the specific heat capacity.

5. RESULTS OF THE VALIDATION

During a test flight with an **Airbus A340-600** the **temperature profiles** were recorded for 23735 s. Temperature measurements were taken at the inlet of the supply duct, at the inlet of the cabin and in the cabin (see FIG. 1, FIG. 3 and FIG. 6). Different tests were carried out during the flight. These tests changed the cabin parameters drastically. The change in cabin parameters has to be taken into account when looking at results from the cabin simulation. For the validation in this paper only the data sets from cabin zone 7 were used.

The **validation of the FLECS components** is done by a comparison of simulated and measured temperature profiles. Almost all component parameters were left as initially set. However a few unknown parameters had to be identified with the simulation: a) The ambient temperature of the ducts was not recorded during the flight test and was hence unknown. b) The heat capacity of the cabin inlet was unknown due to its irregular shape.

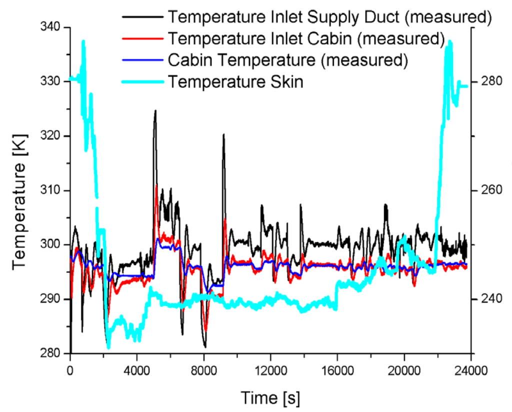

FIG. 6 Measured datasets of supply duct inlet temperature (—), the cabin inlet temperature (—), the cabin temperature (—) and the skin temperature (—).

The air distribution network is characterised by the following parameters (the actual values used in the simulation are proprietary to Airbus and can not be published in this paper):

Duct parameter:

- Length
- Diameter
- Thickness Wall
- Thickness Isolation
- Specific Heat Capacity Wall
- Specific Heat Capacity Isolation
- Density Wall
- Density Isolation
- Heat Conductivity coefficient
    - Wall
    - Isolation

The duct parameters can be calculated by the known geometry or looked up for the used materials. These parameters are fixed during the simulation.

Boundary conditions for the simulation:

- Constant volume flow
- Temperature profile at the supply duct inlet

Parameter identification was use to find the ambient temperature of the ducts because this parameter was not measured during the test flight. From other test flights the range for the ambient temperature is known to differ within a range of 10 °C … 15 °C (283.15 K … 288.15 K) for the flight conditions of this test. For the simulation an ambient temperature of 12.5 °C = 285.65 K was selected. This value gave the best match between simulated temperature profiles and measured values and falls within the reasonable range for this parameter.

In addition to the given duct parameters, the cabin inlet had to be defined. Within the air distribution network the flow velocity differs in the range 10 m/s … 20 m/s. At the cabin inlet the velocity is reduced to around 1 m/s … 2 m/s. Therefore, the heat capacity of the cabin inlet plays an important role. The thermal capacity of an airflow system defines the dynamic. The higher the capacity the more the dynamic response of a system is damped and delayed.

The cabin inlet can be described by the same model as the ducts. The heat capacity of the cabin inlet can be adjusted changing the length of the inlet. The required flow velocity defines the diameter and the density is defined by the used materials.

Cabin inlet parameter:

- Length
- Diameter
- Thickness wall
- Thickness isolation
- Specific heat capacity wall
- Specific heat capacity isolation
- Density wall
- Density isolation
- Heat conductivity coefficient:
    - Wall
    - Isolation

Heat capacities cabin inlet:

- Heat capacity wall: 5702 J/K
- Heat capacity isolation: 143 J/K

The two parameters, duct ambient temperature and air inlet length were identified with the aim of reaching a best fit of the dynamic response of the system. The heat capacity is given above (instead of the length) because this is the end result and important for the simulation.

Another factor, which has an influence on the dynamic, is the **discretisation of the duct components**. For the simulation, each duct was divided up into 5 equal pieces. This led to much different results compared to no discretisation of the ducts. However, an even finer discretisation e.g. into 10 equal pieces led to almost the same results as obtained with 5 equal pieces (a temperature difference of less than 0.58 K).

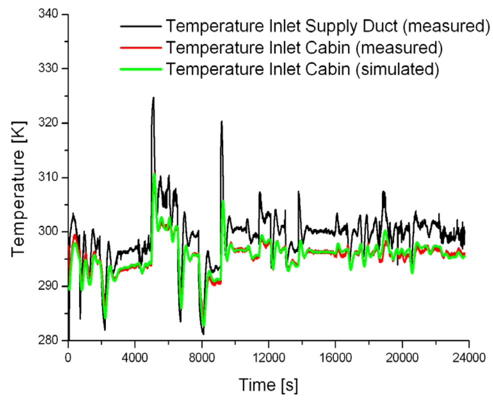

FIG 7. Measured datasets of supply duct inlet temperature (—), the cabin inlet temperature (—) and the simulated cabin inlet temperature (—).

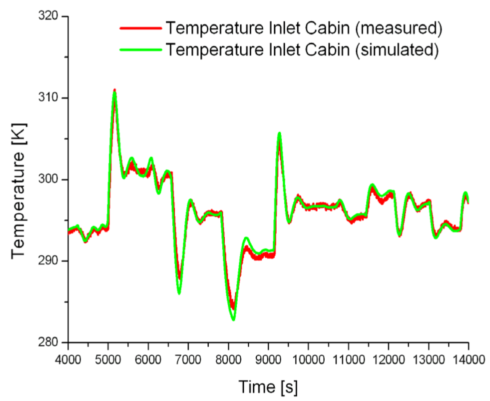

FIG 8. In comparison to FIG. 7: FIG. 8 zooms in to the time range 4000 s … 14000 s.

The simulated response of the duct system compared to the input temperature profile is shown in FIG. 7. The overlap between the measured and the simulated cabin inlet temperature is obvious. In the time range 4000 s… 14000 s the average temperatures of the measured and the simulated dataset have a deviation of 0.07 K. Also the dynamic response of the real system can be reproduced by the simulation model (see FIG. 8). In comparison to FIG. 7, FIG. 8 zooms in to the time range 4000 s … 14000 s

The cabin of the Airbus A340-600 consists of 8 zones. Only the measured data of cabin zone 7 is considered in the simulation. The simulation model of the cabin is described by the following parameters (the actual values used in the simulation are proprietary to Airbus and can not be published in this paper):

Ambient conditions (A340-600 test flight):

- Flight altitude
- Skin temperature
- Mach number

Cabin zone 7 parameters (A340-600):

- Air volume
- Mass interior
- Specific heat capacity interior
- Exchange surface cabin/floor
- Exchange surface interior
- Exchange surface cabin/skin
- Number windows
- Area windows
- No passengers
- No galley
- Convection heat transfer coefficient:
    - Skin
    - Floor

The skin temperature was measured during the flight (see FIG. 6). The skin temperature changes between -41.98 °C = 231.17 K and 14.38 °C = 287.53 K. The flight altitude varies between 0 ft … 41000 ft. The cabin pressure has been assumed to a fixed value of 752 hPa. This value corresponds to a cabin altitude of 8000 ft. No passengers or dummies were present in zone 7 during the test flight. Cabin zone 7 overall electrical heat loads were:

- Heat load skin
- Heat load floor
- Heat load electrical (IFE + lights)
- Heat load solar

Heat capacities of cabin zone 7:

- Heat capacity air
- Heat capacity interior

Compared to the air distribution network, the cabin interior can only be described in a simplified way by means of a representative mass, a specific heat capacity and an assumed exchange surface. The thermal capacities of the aircraft skin and the cabin floor are neglected.

These crude assumptions have a detrimental effect on the accuracy of the simulation results. The advantage of a simplified cabin interior model is however given by the fact that the few parameter of the model as described above, can be easily identified from measured cabin temperatures.

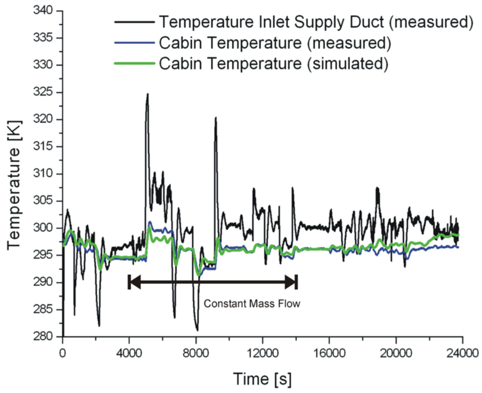

FIG. 9 Measured datasets of supply duct inlet temperature (—), the cabin temperature (—) and the simulated cabin inlet temperature (—).

Due to the simplifications of the cabin interior, the simulated cabin temperature cannot map the measured cabin temperature with the same accuracy (see FIG. 9) as it was the case with the simulation of cabin inlet temperature (see FIG. 8).

Additional deviation between measured and simulated data is due to the fact that during the flight different test were carried out. For example the recirculation was switched off. Note: In the time range as shown in FIG. 9 and FIG. 10 the airflow and recirculation was kept constant. This guarantees a useful comparison between measurements and simulation for this case.

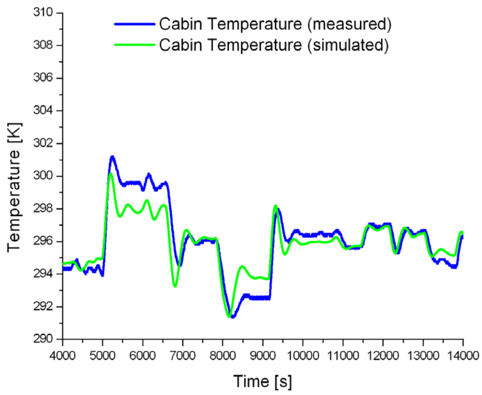

FIG. 10 In comparison to FIG. 9: FIG. 10 zooms in to the time range between 4000 s … 14000 s.

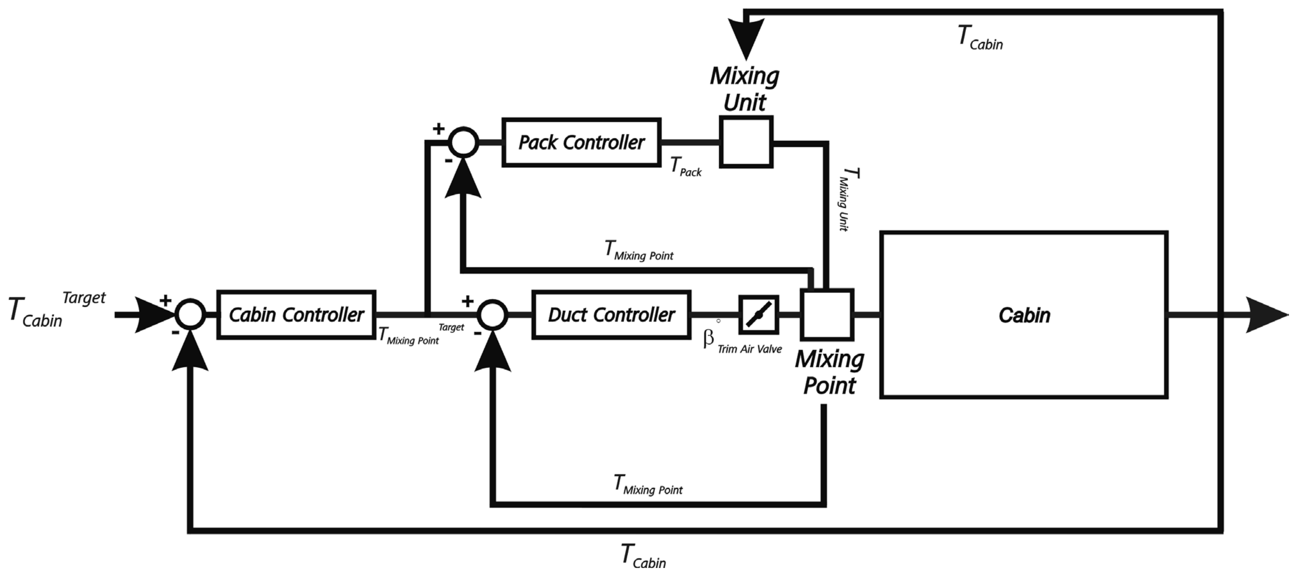

FIG. 11 The control aspects of a cabin simulation.

6. SIMULATION OF AIRCRAFT CABIN TEMPERATURE CONTROL

A schematic of an environmental control system of an aircraft consisting of 2 zones is shown in FIG. 1 and explained in Section 2. Temperature control details follow from FIG. 11: The cabin & duct controller is a serial connection of a PI-type cabin controller, which defines the target temperature for the duct controller. The controlled variable of the cabin & duct controller is the supply temperature in the mixing point. The actuating variable of the duct controller is the angular velocity of the angle of the trim air valve. The temperature of the pack is controlled by the pack controller. Control algorithms used in the simulation are those proprietary to the equipment manufacturer. Individual simplified control algorithms could be defined based on the control principles explained.

Validated FLECS components (as discussed above) were used to build up a simulation of a generic single aisle air distribution network and aircraft cabin model. The cabin is separated in two zones that are assumed to be identical. Each zone has its own trim air valve (see FIG. 14).

A representative mass of the interior can be found assuming 20 kg/passenger, an assumed exchange surface of the interior may follow from 2 m²/passenger or 0,1 m²/kg.

The pack is not simulated in detail; instead, a mass flow source is used as simplified pack model. The air of the cabin is recirculated by a fan into the mixing unit. The overall mass flow is fixed to 1.8 kg/s. The fan parameters are chosen in a way that 50 % of this mass flow is contributed by the pack the other 50 % are contributed by the recirculation.

Parameters and values as used in the generic simulation are given.

Total cabin (zone 1 plus zone 2) parameters :

- Air volume: 200 m³
- Mach number: 0.82
- Mass interior: 4000 kg
- Specific heat capacity interior 1000 J/(kg K)
- Exchange surface cabin/floor: 50 m²
- Exchange surface interior: 400 m²
- Exchange surface cabin/skin: 200 m²
- Number passengers: 200
- Number flight attendances: 6
- Number service personal: 6
- Number windows: 52
- Area windows: 0.1 m²
- Overall heat transfer coefficients:
  - Skin: 1.2 W/(m² K)
  - Floor: 2.5 W/(m² K)

Cabin overall heat loads:

- Heat load galley:
  - Ground: 1800 W
  - Flight: 2400 W
- Heat load solar:
  - Ground: 0 W
  - Flight: 7020 W
- Heat load electric:
  - Ground (0 s …1200s): 5842 W
  - Ground (1200 s … 2400s): 5821 W … 6521 W
  - Flight: 7101 W
- Heat load skin: -5587 W … 81 W
- Heat load floor: -150 W … 42 W
- Heat load passengers: ~ 75 W per passenger

The following test case for a dynamical simulation of the environmental control system of a cabin consisting of 2 zones is defined.

Test Case:

Time: 0 s … 1200 s
The aircraft is on ground. The ambient conditions are described by a temperature of 20 °C = 293.15 K and a pressure of 1013 hPa. The skin temperature is assumed to be 20 °C (cloudy day). The target temperature of the cabin is also 20 °C. In each cabin zone 3 person of the service personal and 3 flight attendances are working.

Time: 1200 s … 2400 s
The aircraft is on ground. The service personal is leaving the cabin and the boarding starts. The target temperature of the cabin is 20 °C. In 20 minutes 200 passengers enter the cabin, assuming a constant flow of passengers. The heat load, which flows into the cabin, increases drastically (see FIG. 12).

Time: 2400 s … 8400 s

2400 s: The boarding is completed. The aircraft starts. In 990 s the aircraft climbs to a flight altitude of 33000 ft (climb rate 2000 ft/min). The ambient conditions are described by an ISA condition. Knowing the ambient temperature $T_{ambient}$ the skin temperature T_{skin} can be calculated [1] ($T_{skin}=T_{ambient}\,(1 + 0.18\,M^2)$, M: Mach number). The target temperature of the cabin zone 1 is 22 °C = 295.15 K, the target temperature of the cabin zone 2 is 24 °C = 297.15 K. The cabin pressure is fixed to 752 hPa. This value corresponds to a cabin altitude of 8000 ft.

The simulated temperature profiles in zone 1 and zone 2 are shown in FIG. 12. In the time range 0 s … 1200 s the simulation has to tune itself. At the end the target temperature of 20 °C = 293.15 K is reached. During the boarding the temperatures rise up. The reason for that is the increasing heat load of the passengers. The chosen pack mass flow 0.9 kg/s is too small to control the temperature of the cabin to 20 °C. The ambient temperature in an altitude of 33000 ft is -50.4 °C = 222.75 K. During the climb flight of the aircraft the skin temperature falls from 20 °C to -24.5 °C (293.15 K … 248.65 K). As a result the cabin loses a huge amount of heat. The temperature in the cabin is controlled to 22 °C = 295.15 K (zone 1) and 24 °C = 297.15 K (zone 2) (see FIG. 12). In the first 150 s the temperatures rise up. As a result of the falling skin temperature, the target temperatures cannot be reached. The zone temperatures start to sink. Not until the flight altitude has reached the maximum value the temperature can be controlled to the target values.

The control behaviour of the cabin & duct controller is shown in FIG. 13. The trim air valve has a minimum opening angle of 5°. In the first 2400 s the trim air valve is fixed to this minimum angle. Only a small amount of hot bleed air flows into the system. Correlated with the start of flight the valves open. The valve angles increase. The dynamic of the trim air valve of zone 2 differs clearly compared with the dynamic of the trim air valve of zone 1.

At the time when the target temperatures are reached the opening angle of trim air valve 1 approach 7.8° the limit of the opening angle of trim air valve 2 is 21.7°.

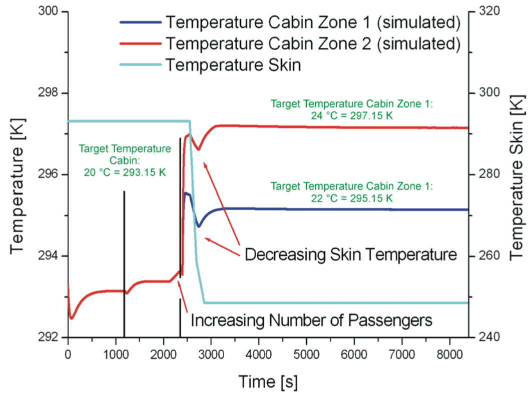

FIG. 12 Simulated temperature profiles in zone 1 (—) and zone 2 (—) and the used skin temperature profile (—).

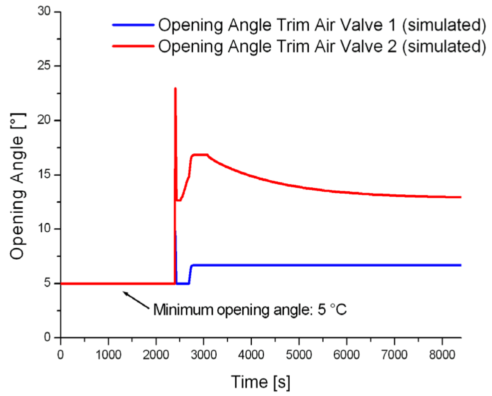

FIG. 13 Opening angle of trim air valves of zone 1 (—) and zone 2 (—).

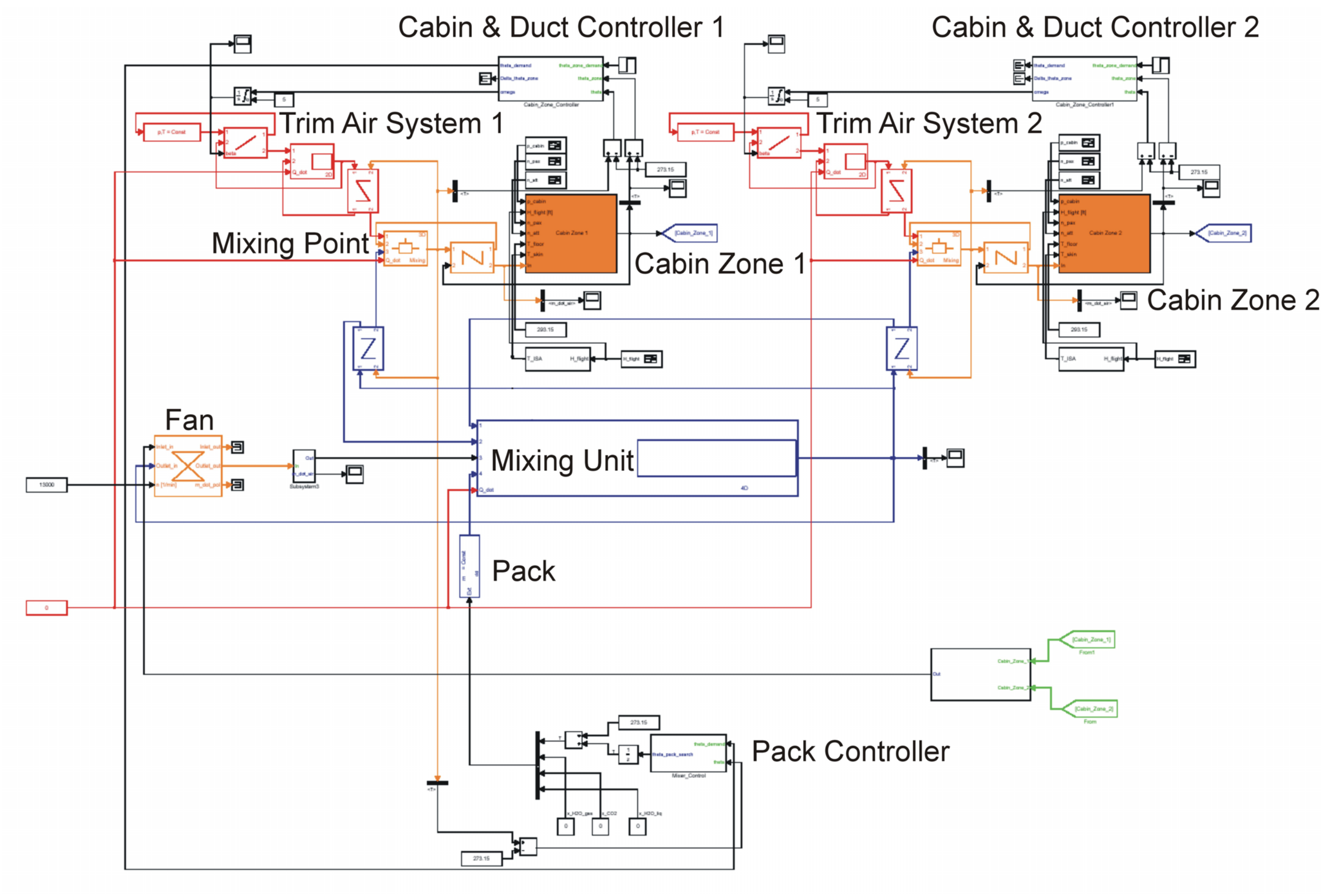

FIG. 14 Simulink configuration of an environmental control system of a cabin model consisting of 2 zones (see FIG. 11 and FIG. 5).

7. SUMMARY

An introduction into the thermal behaviour and the temperature control of an aircraft cabin including its air distribution network is given. The discussed simulation models are based on generic FLECS database components. Ducts can be defined with help of a generalised flow resistance and a volume element. Heat transfer takes place through the duct wall. The air distribution network can be built up from several duct elements. Heat transfer with respect to the cabin can be modelled with FLECS heat transfer units for conduction, convection and radiation. In combination with a simplified cabin model an environmental control system can be simulated. The different components can be parameterised with aircraft specific values. Most values follow from the aircraft geometry or material properties. Rough assumptions of other parameters can be obtained from this paper.

The simulation model just described was compared with measured data recorded during a test flight of an Airbus A340-600. The measured temperature profiles and the simulated ones were in good agreement. Especially the temperature profile at the cabin inlet could be almost perfectly reproduced.

The simulation result of the cabin temperature showed certain deviations. These deviations could be explained with the simplified form of the cabin model. Parameters of the simple cabin model can easily be identified in a comparison between measured data and the simulation. In this way, parameters for different aircraft cabins could be obtained. In this paper parameters of the cabin inlet were identified.

The thermal capacities of the cabin skin and the cabin floor were neglected. The inclusion of these parameters in future work could lead to improved results.

With the help of the validated components the temperature control concept of an ECS of an aircraft consisting of 2 zones was discussed. The temperature control concept of an ECS requires two independent controllers.

A highly dynamic test case was defined and simulated. The results show a reasonable behaviour.

Next steps in the research will be devoted to the simulation of further ECS components.

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